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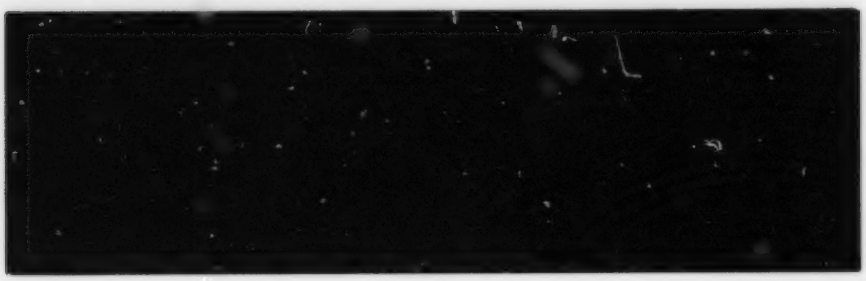

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A MICRO-COMPUTER PROGRAM FOR ESTIMATION OF DETONATOR OVERLAP PROBABILITY

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A MICRO-COMPUTER PROGRAM FOR ESTIMATION OF DETONATOR OVERLAP PROBABILITY

by

Yves C. Lizotte

ABTRACT

The use of a micro-computer program for estimation of detonator overlap probability is described in this text. Input data can be provided directly on the screen by responding to prompts or with a data file. The main results appear on the screen and an output file can be written for text processing and hard copy. The problem of detonator firing time variations, or cap scatter, is briefly reviewed and the terminology for quantifying variations is defined. Examples illustrate the use of the program, its limitations and the effects of variations on overlap probability. The influence of cap scatter on fragmentation is discussed. References are provided and the annotated listing of the program is appended.

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Key words: Micro-computer, blasting, detonators, overlap, probability

UN LOGICIEL MICRO-INFORMATIQUE POUR ESTIMER LA PROBABILITÉ DE CHEVAUCHEMENT DES DÉTONATEURS DE SAUTAGE

par

Yves C. Lizotte *

RÉSUMÉ

L'utilisation d'un logiciel micro-informatique pour estimer la probabilité de chevauchement de détonateurs de sautage est décrite dans ce document. Les données d'entrée peuvent être fournies directement en répondant aux questions apparaissant sur l'écran ou avec un fichier de données. Les principaux résultats apparaissent sur l'écran et un fichier de résultats peut être édité pour impression. Le problème de variations du temps de tir des détonateurs est résumé et la terminologie pour quantifier ces variations est définie. Les exemples illustrent l'utilisation et les limitations du programme, ainsi que les effets des variations sur la probabilité de chevauchement. Les références sont fournies et le logiciel annoté est annexé.

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Mots clés: Micro-ordinateur, sautage, détonateurs, chevauchement, probabilité

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1. INTRODUCTION

It is generally recognized that detonator caps used for initiating explosives for rock blasting do not fire at precisely the times stipulated by the detonator manufacturer. This is named delay variability or cap scatter and can significantly affect the results of multi- detonator blasts. A blast can be adversely affected by detonator variability in two ways:

- Detonator overlap causes out-of-sequence detonations. Because multi- delay blasts are designed to create a *free face* for each consecutive hole to be blasted, the out-of-sequence detonation will reduce crack propagation, fragmentation, and effective utilization of the energy of the explosive gases. The worst case which can arise is total failure of the blast.

- Detonator crowding whereby the time interval between consecutive holes to be fired is insufficient to enable adequate crack propagation and commencement of rock motion to create a *free face*. In this situation the compressive wave can produce *dead packing* or *precompression* of the explosives in the next hole to be fired.

The accuracy of electric detonators is not a new problem. Users have become more aware of the problems created by inaccurate firing times because of numerous studies on the subject and the greater availability during the last decade of instrumentation to verify millisecond delay initiation times. Manufacturers have strived to increase the accuracy of electric detonators; however, the manufacture and mechanism of detonation itself induce variability in firing times. Recent studies have shown the benefits of electronic detonators, producing improved fragmentation and lower vibrations. It appears that the industry is not yet ready to accept the incremental cost of these detonators to achieve these benefits. The estimation of the probability of detonator overlap firing time or crowding for a specified blast initiation pattern can indicate if problems can be expected. The designer can consider the results of such simulations and, by trial and error, improve the probability of success of his/her blast.

2. TERMINOLOGY

The absence of a standard terminology for specifying and reporting detonator variability is of concern. (In some instances the measured variability is insufficiently qualified to be of any other use than to boast about the poor quality of detonators). For example, maximum scatter expressed in $\pm$ milliseconds from field measurements is of little value by itself, without qualifying with numbers tested, nominal firing times and if detonators were from the same batch, different batches or different manufacturers. Similarly, specifying scatter in terms of $\pm$ a percentage of nominal time can be misleading; if, say, a sample of thirty detonators were tested and scatter is reported as $\pm 8\%$ this could mean in statistical terms

that the standard deviation of scatter is about 4%, assuming the sample is representative of a source population which is normally distributed (the sample is assumed to represent 95% of the source population which is approximately contained within plus or minus two standard deviations). Manufacturers normally specify for their products the amount of variability expected within a batch as a percentage standard deviation. It is generally well accepted that longer delay period detonators will have greater variations because of the pyrotechnic mechanism operation, and thus justifies an overall specification of scatter as percentage of nominal time. Heilig and Mackenzie (1988) tested more than 5000 detonators and show that sample scatter is only a fraction of total scatter; the percentage offset from the nominal mean for a batch was in the range 0-10 and the total scatter percentage was in the range 5-15 for the 95 percentile.

For simplifying the issue, the program described herein requires cap scatter be specified for each detonator as a standard deviation, expressed in the same time units as nominal times. This requires more input than a single percentage but offers greater flexibility. Note that in the examples the scatter is expressed as a percentage standard deviation.

3. MATHEMATICAL BACKGROUND

The principle of operation of the simulation program is relatively simple. However, it is necessary to review the statistical concepts and the computational procedures used in order to avoid misinterpretations of results and make sure the user is aware of the limitations of results. The operating principle and core program code is based on the work of Rholl and Stagg (1988) from the U.S. Bureau of Mines. Additional technical papers where these authors have made use of the program are referenced.

The simulation program consists of "sampling" detonator time distributions in pairs and measuring if overlap times occur; the process is repeated a great number of times until a representative sample is obtained - at least one thousand simulations should be made for each pair of detonator times which are compared. The first limitation of the program is that detonators are only compared to the two adjacent detonators specified; for large delay variabilities this does not consider overlap times can occur for non-adjacent detonators.

3.1 Random Numbers

The simulation procedure used is the Monte-Carlo process. This consists of using a seed number to initiate a random number generator. Although most computers have functions for generating random numbers a subroutine is part of the program so it can be machine-independent. The seed must be a number in the (0,1) interval and is referred to as a random digit. The series of random numbers should be uniformly distributed between zero and one; it is equiprobable to generate a number between, for example, zero and 0.1

than between 0.9 and 1.0. The sequence of random numbers is actually pseudo-random since a specified seed will always produce the same sequence of random digits. This is useful for program validation but can conceivably bias results since a random digit seed can produce non-uniformly distributed random digits. It is thus recommended to execute the program with more than one seed to increase representativity of results. This also indicates that program results should be considered as qualitative assessments rather than absolute numerical values.

A random number generator should have four qualities: computationally efficient (easy and fast to produce numbers), seed independent, a long periodicity (sequence before numbers start repeating) and uniformly distributed which measures the degree of randomness. To test seed dependency and randomness a χ^2 statistical test was done. Generated numbers are grouped in classes over the (0,1) interval. The chi-square goodness of fit test verifies that observed frequencies in each class are sufficiently close to the observed frequencies if data did, in fact, come from a uniform distribution. The test is then made with the following calculation:

$$C = \sum_{i=1}^{n} \frac{(O_i - E_i)^2}{E_i} \qquad [1]$$

where:

O_i = observed number in ith class;

E_i = expected number in ith class = T/n;

T = total number of observations;

n = number of classes.

The value of C is to be compared with the value $\chi^2_\alpha(n-1)$ which comes from a chi-square distribution with n-1 degrees of freedom with a level of significance α. If the test statistic given with the above summation is greater than $\chi^2_\alpha(n-1)$, then the uniform generator should be viewed with suspicion.

3.2 Normally Distributed Random Variables

The variability in detonator firing time is assumed to be normally distributed. It is then necessary to use the random digits to generate random variables which are normally distributed, with a mean of μ and a standard deviation of σ for each detonator. Several procedures are available to generate normally distributed random variables; the method proposed by Hillier and Lieberman (1986) has been adopted and is described below.

"A particularly simple technique for generating a random observation from a normal distribution is obtained by applying the central limit theorem. Because a random decimal number essentially has a uniform distribution from 0 to 1, it has a mean of $\frac{1}{2}$ and standard deviation $\frac{1}{\sqrt{12}}$. Therefore, this theorem implies that the sum of n random decimal numbers has approximately a normal distribution with a mean $\frac{n}{2}$ and standard deviation $\sqrt{\frac{n}{12}}$. Thus if $r_1, r_2, ..., r_n$ are a sample of random decimal numbers, then:

$$x = \frac{\sigma}{\sqrt{\frac{n}{12}}} \sum_{i=1}^{n} r_i + (\mu - \frac{n}{2}) \frac{\sigma}{\sqrt{\frac{n}{12}}} \qquad [2]$$

is a random observation from an approximately normal distribution with mean μ and standard deviation σ. This approximation is an excellent one (except in the tails of the distribution), even with small values of n. Thus values of n from 5 to 10 often are used; n = 12 also is a convenient value, because it eliminates the square root terms from the preceding expressions."

For n =12 equation [2] is simplified to:

$$x = \sigma \sum_{i=1}^{12} r_i + \mu - 6\sigma \qquad [3]$$

Thus a detonator time can be generated in the range $\mu \pm 6\sigma$ (although the probability of generating a value out of the $\mu \pm 3\sigma$ is very small). Twelve numbers are used to generate each detonator firing time for each simulation. A data set with 15 detonators and 5000 simulations requires 600000 random digits to be generated, which can explain the length of time for program execution. Note that the technique could reduce randomness if the random number generator has a short period before cycling.

4. USE OF PROGRAM CAP3.FOR

The micro-computer program for estimating detonator overlap probability is on the diskette provided with this text, in FORTRAN code and in executable form. It is started by typing "CAP3". A series of questions are then to be answered. When an answer is completed the "Return" key is hit. The first message to appear will be:

```
ENTER NUMBER TO INITIATE RANDOM NUMBER GENERATOR
ANY NUMBER BETWEEN ZERO AND ONE CAN BE USED
```

A random digit must then be specified. The next prompt appearing is:

```
SELECT THE METHOD OF SPECIFYING INPUT DATA
TYPE ''1'' FOR SCREEN, ANY OTHER FOR DATA FILE
```

"1" is typed for keyboard entry, any other number for a datafile to be read. The user responds to a series of prompts if keyboard entry is requested, or specifies a data file for batch input.

Keyboard entry

The next prompts with this option are:

```
WRITE THE TITLE OF SIMULATION
WRITE NUMBER OF ITERATIONS, NUMBER OF CAPS, CROWDING INTERVAL
AND THRESHOLD
```

A title up to 70 alpha-numeric characters can be used. The recommended minimum number of iterations is 1000. A crowding interval can be used instead of zero to consider firing times which do not overlap but are insufficiently spaced in time for efficient blasting. The threshold value usually used is 1, which means 1 overlap is required to consider the blast as misfiring. For each detonator the following question must be answered:

```
SPECIFY MEAN FIRING TIME AND STANDARD DEVIATION
FOR DETONATOR: nn
```

When firing times and standard deviations are specified for all detonators the program then computes the probability of overlap. The location of result display is then requested:

```
AT THE ''UNIT 8?'' PROMPT SPECIFY OUTPUT FILE LOCATION AND NAME
IF NO FILE IS REQUIRED TYPE ''CON''
UNIT 8?
```

The user responds accordingly. In both cases the probability and summary results appear on the screen.

Batch file entry

For large sets of data and several executions, batch entry is preferable. A simple text processor is required. The first prompt is:

```
TYPE THE NAME OF DATA FILE AT UNIT 4? PROMPT
```

The input data file location and name is then entered. This file contains the following information:

Line 1:	**Title of simulation**
Line 2:	**Number of iterations, number of detonators, crowding interval and threshold**
Line 3 to xx:	**Mean firing times for detonators 1 to m**
Line xx+1 to yy:	**Standard deviation of times for detonators 1 to m**

An example of a batch input file is provided in Example 2 below. The procedure for output reporting is the same as for keyboard entry output previously explained.

5. EXAMPLE 1

This first example is simple and shows how information is specified with keyboard entries. A comparison is made between detonator overlap probabilities for two detonators, first with standard deviations of 12ms, then with standard deviations of 9ms. The keyboard entry session for one program execution would be as follows:

```
 --> CAP3   (--> indicates keyboard entries)
ENTER NUMBER TO INITIATE RANDOM NUMBER GENERATOR
ANY NUMBER BETWEEN ZERO AND ONE CAN BE USED
--> 0.3245
SELECT THE METHOD OF SPECIFYING INPUT DATA
TYPE ''1'' FOR SCREEN, ANY OTHER FOR DATA FILE
--> 1
WRITE THE TITLE OF SIMULATION
--> Example 1 - Two detonators with standard deviation = 12ms
WRITE NUMBER OF ITERATIONS, NUMBER OF CAPS, CROWDING INTERVAL
AND THRESHOLD
--> 1000 2 0 1
SPECIFY MEAN FIRING TIME AND STANDARD DEVIATION
FOR DETONATOR: 1
--> 100 12
SPECIFY MEAN FIRING TIME AND STANDARD DEVIATION
FOR DETONATOR: 2
--> 125 12
AT THE ''UNIT 8?'' PROMPT SPECIFY OUTPUT FILE LOCATION AND NAME
IF NO FILE IS REQUIRED TYPE ''CON''
UNIT 8?
--> con
```

The following results will scroll on the console monitor.

```
Example 1 - Two detonators with standard deviation = 12ms
SIMULATED COMPUTATION OF OVERLAP PROBABILITY
NUMBER OF DETONATORS:      2
NUMBER OF ITERATIONS:   1000
CROWDING INTERVAL:       0.0
THRESHOLD:                 1
INITIAL SEED FOR RANDOM NUMBER GENERATOR:   .32450000
```

```
PROBABILITY OF OVERLAP:    .08000
DELAY          NOMINAL          STANDARD          NUMBER OF
NUMBER         FIRING TIME      DEVIATION         OVERLAPS
  1             100.00           12.00              80
  2             125.00           12.00              80
PROBABILITY OF OVERLAP:    .08000
```

Figure 1 shows the comparison of overlap probabilities when standard deviations are modified from 12ms to 9ms. This figure is a compilation of several simulations. The average overlap probability for 12ms is 7.4% and 3.4% for 9ms. Note the difference for several simulations compared to a probability of 8.0 % noted in the keyboard session detailed above.

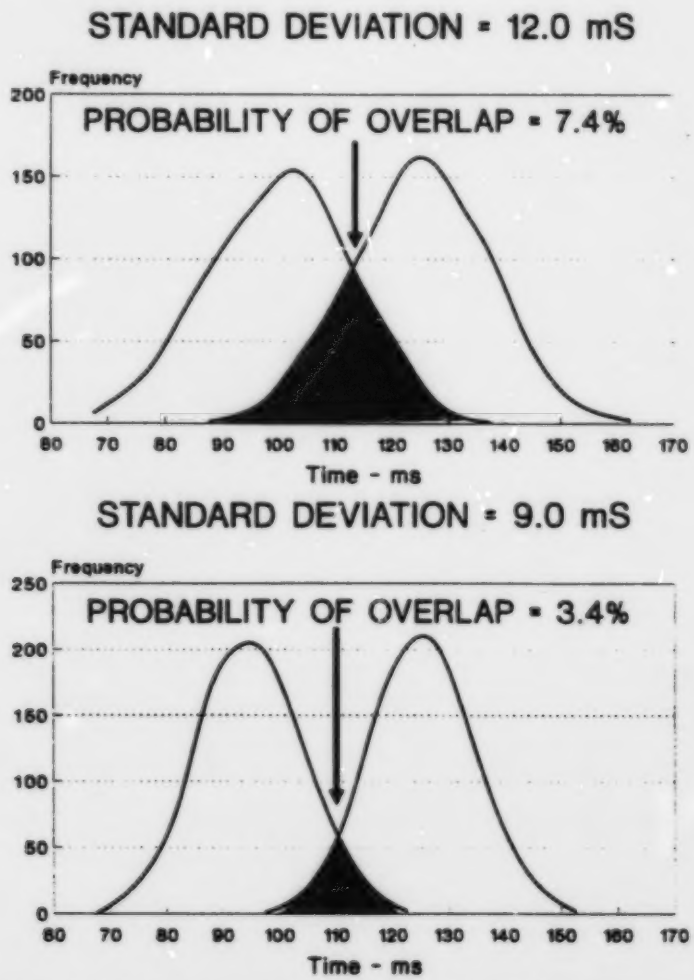

Figure 1. Illustration of detonator overlaps - two detonators

6. EXAMPLE 2

This example shows the use of an input data file when simulations involve several detonators. In this case fifteen detonators with nominal time differences of 25ms would be assessed for standard deviations of 4% and 6% respectively. The program would be executed in the same way, until the input option is requested. On the diskette EXAMP2.DAT contains a typical data file with the following information:

```
PROBABILITY OF OVERLAP - 15 DETONATORS S.D. =4%
15 1000 0 1
25 50 75 100 125 150 175 200 225 250 275 300 325 350 375
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
```

The result of this simulation is in file EXAMP2.OTP on the diskette and is listed below:

```
PROBABILITY OF OVERLAP - 15 DETONATORS S.D. =4%

SIMULATED COMPUTATION OF OVERLAP PROBABILITY

NUMBER OF DETONATORS:      15
NUMBER OF ITERATIONS:    1000
CROWDING INTERVAL:        .00
THRESHOLD:                 1
INITIAL SEED FOR RANDOM NUMBER GENERATOR:     .12400000

PROBABILITY OF OVERLAP:              .40100

DELAY    NOMINAL        STANDARD    NUMBER OF
NUMBER   FIRING TIME    DEVIATION   OVERLAPS

    1      25.00          1.00        0.
    2      50.00          2.00        0.
    3      75.00          3.00        0.
    4     100.00          4.00        0.
    5     125.00          5.00        1.
    6     150.00          6.00        3.
    7     175.00          7.00       12.
    8     200.00          8.00       24.
    9     225.00          9.00       45.
   10     250.00         10.00       64.
   11     275.00         11.00       92.
   12     300.00         12.00      134.
   13     325.00         13.00      190.
   14     350.00         14.00      233.
   15     375.00         15.00      118.
```

The illustration of probability distributions are presented in Figures 2 (σ =4%) and 3 (σ =6%). The probability of overlap is approximately double for this change (probability of 42% increases to 78%). This example and the illustrations demonstrate that for high variability of detonation times it is possible to get overlap of firing times between non-adjacent detonators. This overlap seen in Figures 2 and 3 is not accounted for in the simulation program as it is structured now. It can be estimated by executing the program again with only every other detonator specified, and subsequently adding this probability to the initial estimate.

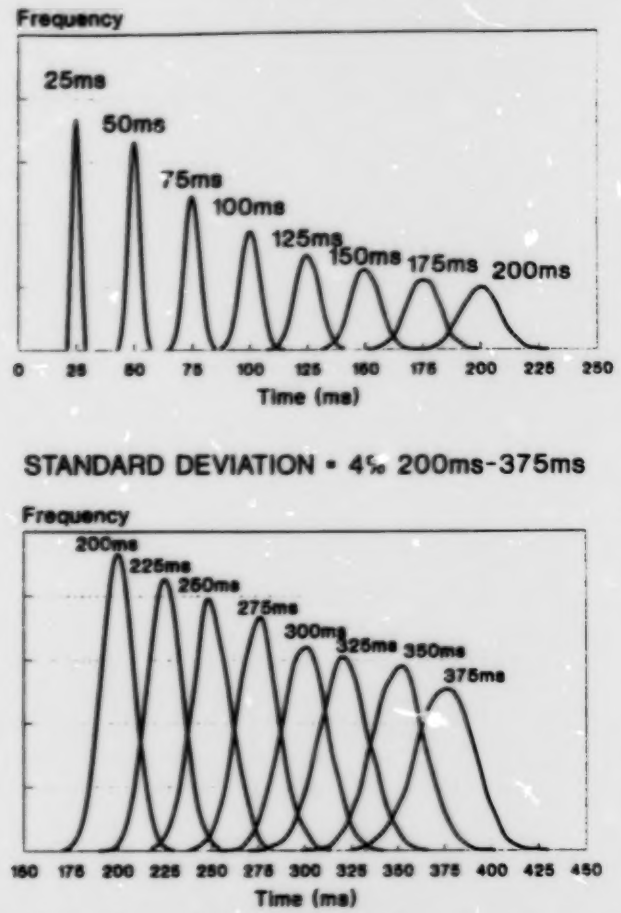

Figure 2. Illustration of overlaps - fifteen detonators, σ =4%

7. DETONATOR VARIABILITY AND FRAGMENTATION

The studies on delay variability and timing conclude that more accurate detonators will improve fragmentation. It is difficult to specify rigid numerical rules for all conditions other than some approximation as to the desired level of accuracy and indicate the basic equations for this purpose. The influence of detonator variability on fragmentation is similar to the influence of delay timing on fragmentation. Extrapolation of results and empirical rules from detonator timing studies is difficult unless these studies were done with high accuracy detonators.

Two equations can be of use to consider required accuracy or assessing if cap accuracy is sufficient. The first equation is by Winzer described by Bajpayee and Mainiero (1990) and the Winzer Index can be used to compare accuracies:

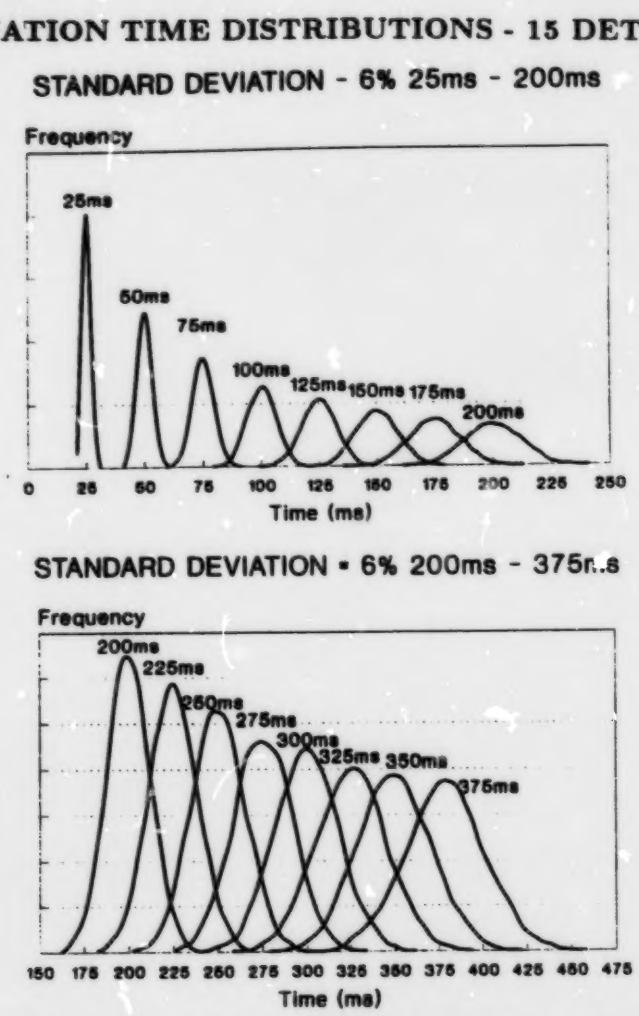

Figure 3. Illustration of overlaps - fifteen detonators, σ =6%

$$W = \frac{TH - TL}{(SH^2 + SL^2)^{1/2}} \qquad [4]$$

where,

TH = average delay time for a group of detonators of a given delay period, seconds;

TL = average delay time for a group of detonators of the next lower period, seconds;

SH = standard deviation of the group corresponding to TH, seconds;

SL = standard deviation of the group corresponding to TL, seconds;

According to Winzer a value of 3 or less for the Winzer index will indicate a significant probability of overlap between adjacent delay periods. In statistical terms this corresponds

to approximately the 99.865 % probability that no overlap would occur. In a comprehensive field study of the effect of accurate delays on fragmentation, Stagg and Rholl (1987) present a more general statistical analysis equation, to determine if cap accuracy is sufficient to maintain at least some minimum delay at a given probability:

$$\sigma_d \leq \frac{\mu_d - \lambda B}{Zcl} \qquad [5]$$

where,

$\sigma_d = \sqrt{\sigma_a{}^2 + \sigma_b{}^2}$ = Standard deviation of the difference in the firing times.

μ_a, σ_a = Mean firing time and standard deviation of cap a.

μ_b, σ_b = Mean firing time and standard deviation of cap b.

$\mu_d = \mu_a - \mu_b$ = Difference in the mean firing times ($\mu_a > \mu_b$)

B = Burden expressed in meters or in feet.

λ = Delay between holes expressed in ms/m or ms/ft.

Zcl = Number of standard deviations at a given confidence (probability) level.

Stagg and Rholl (1987) suggest that fragmentation requires a minimum value for λ of 2.3 to 3.3 ms/m (0.7 to 1.0 ms/ft). These values have only been verified for single-row shots with no decking. Rholl and Stagg (1988) also mention that crowding is avoided and regulations to control ground vibrations are respected if a minimum of 8ms between detonators is maintained. This is generally sufficient to allow burden relief. They also suggest that delays longer than 16ms/m (5 ms/ft) increase the risk of cutoff of the explosive column.

Pre-split and smooth blasting is related to fragmentation whereby large fragmentation produced by blasting may be the result of caving, slabbing and sloughing. For these techniques it is desired to have explosive charges fired simultaneously. Heilig and McKenzie (1988): "Tansey has indicated that crack growth velocities to be approximately one third the p-wave velocity of the rock. Using this figure, the time for a crack to propagate from one blasthole to another (approx 1.0m) in a development round is less than 1 millisecond, assuming a p-wave velocity greater than 4500m/s. Knowledge of the statistics of delay timing permits the calculation of the probability that adjacent holes will detonate within this time interval." Future studies and field investigations with high accuracy detonators, such as electronic detonators, will help the blasting engineer specify to the manufacturer the desired level of accuracy. The author hopes the program described herein will be useful to the blasting engineer in assessing specific layouts and designs and assist in specifying adequate detonator accuracy.

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APPENDIX A

MICRO-COMPUTER PROGRAM ANNOTATED LISTING

The following pages are the annotated listing of program CAP3. The source code is in file CAP3.FOR on the diskette.

```
C     ------------------------------------------------------
C     This program calculates probability of overlap
C     based on work by S.A. Rholl and M.S. Stagg, USBM.
C
C     Normal distribution approximation 90/03/13
C     Specified random number generator 90/03/13
C     Modified for use on PC - Y.Lizotte 90/11/12
C     Modified for interactive use     90/11/20
C     Variables:
C
C     P:             Probability of overlap
C     XM:            Mean firing time
C     SD:            Standard deviation
C     T:             Detonation time
C     TAU:           Crowding interval
C     THRESHOLD:     Overlap index (Usually 1)
C     M:             Number of caps
C     N, XN:         Number of iterations
C     Index:         Overlap index
C     I,J,K,L:       Counting indexes
C     Z:             Initializes random number generator
C     R:             Initial random number
C     JKN:           Indicates choice of input format option
C                    JKN=1 means screen input
C                    JKN= any other means input data file
C     ------------------------------------------------------
C
      PROGRAM BLAST
      INTEGER*2 THRESHOLD
      INTEGER*4 L,N,INDEX
      CHARACTER FILENAME*40
      CHARACTER*70 TITLE
      REAL*4 NORM
      REAL*8 XM(200),SD(200),CHECKER(200),XN,P,T(200),TAU
      LOGICAL*2 OVERLAP
      WRITE (*,100)
  100 FORMAT(/,3X,'ENTER NUMBER TO INITIATE RANDOM NUMBER GENERATOR:')
      WRITE(*,101)
  101 FORMAT(/,3X,'ANY NUMBER BETWEEN ZERO AND ONE CAN BE USED')
      READ(*,*)Z
      R=RND(Z)
      WRITE(*,105)
  105 FORMAT(/,3X,'SELECT THE METHOD OF SPECIFYING INPUT DATA:')
      WRITE(*,106)
  106 FORMAT(/,3X,'TYPE "1" FOR SCREEN, ANY OTHER FOR DATA FILE')
      READ(*,*) JKN
      IF(JKN.NE.1) GO TO 205
C     ------------------------------------------------------------
C     Screen entry of information for simulation
C     ------------------------------------------------------------
      WRITE(*,107)
  107 FORMAT(/,3X,'WRITE THE TITLE OF SIMULATION')
      READ(*,'(A70)') TITLE
      WRITE(*,108)
  108 FORMAT(/,3X,'WRITE NUMBER OF ITERATIONS, NUMBER OF CAPS',3X,
     1'CROWDING INTERVAL AND THRESHOLD')
      READ(*,*)N,M,TAU,THRESHOLD
      DO 110 LJN=1,M
      WRITE(*,109)LJN
  109 FORMAT(/,3X,'SPECIFY MEAN FIRING TIME AND STANDARD DEVIATION',
```

```
      1,/,3X,'FOR DETONATOR NUMBER:',3X,I3)
        READ(*,*)XM(LJN),SD(LJN)
  110   CONTINUE
        GO TO 210
C
  205   WRITE(*,200)
  200   FORMAT(/,3X,'TYPE THE NAME OF DATA FILE AT UNIT 4? PROMPT')
        READ(4,'(A70)')TITLE
        READ(4,*)N,M,TAU,THRESHOLD
        READ(4,*)(XM(I),I=1,M)
        READ(4,*)(SD(I),I=1,M)
C       ---------------------------------------------------------------
C       When data file has been read in one form or the other the
C       computations can begin.
C       ---------------------------------------------------------------
  210   INDEX=0
        DO 30 L=1,N
        DO 10 J=1,M
        SRI=0.0
        DO 40 KK=1,12
        SRI=SRI+RND(0.0)
    40  CONTINUE
C       ------------------------------------------------
C       Normal distribution approximation: Hillier and
C       Lieberman, Operations Research, 1986, p.807.
C       ------------------------------------------------
        T(J)=XM(j) +(SD(J)*SRI)-(6.*SD(J))
    10  CONTINUE
        OVERLAP=.FALSE.
        K=0
        DO 20 I=1,M-1
        IF ((T(I+1) -T(I)).LT.TAU) THEN
            K=K+1
          CHECKER(I+1)=CHECKER(I+1)+1
            CHECKER(I)=CHECKER(I)+1
          ENDIF
        IF (K.EQ.THRESHOLD) THEN
            OVERLAP=.TRUE.
            GO TO 20
            ENDIF
    20  CONTINUE
        IF (OVERLAP) INDEX=INDEX+1
    30  CONTINUE
        XN=N
        XINDEX=INDEX
C
        P= XINDEX/XN
C
C       ---------------------------------------------------
C       Ready for output of results - screen or data file
C       ---------------------------------------------------
        WRITE(*,301)
  301   FORMAT(/,3X,'AT THE "UNIT 8?" PROMPT SPECIFY OUTPUT FILE',
     1/,3X,'LOCATION AND NAME',/,3X,'IF NO FILE IS REQUIRED TYPE',
     2/,3X,'  "CON"',//)
        WRITE(8,310) TITLE
  310   FORMAT(/,3X,A70,/)
        WRITE(8,320)
  320   FORMAT(3X,'SIMULATED COMPUTATION OF OVERLAP PROBABILITY',/)
        WRITE(8,330) M, N, TAU, THRESHOLD, Z
  330   FORMAT(3X,'NUMBER OF DETONATORS:',4X,I3,/,3X,
     1'NUMBER OF ITERATIONS:',2X,I5,/,3X,
     2'CROWDING INTERVAL:',6X,F5.2,/,3X,
     3'THRESHOLD:'12X,I3,/,3X,
     4'INITIAL SEED FOR RANDOM NUMBER GENERATOR:',3X,F10.8)
        WRITE(8,300)P
  300   FORMAT(/,3x,'PROBABILITY OF OVERLAP:',2X,F16.5)
        WRITE(8,340)
  340   FORMAT(//,3X,'DELAY',4X,'NOMINAL',7X,'STANDARD',3X,'NUMBER OF',3X
     1/,3X,'NUMBER',3X,'FIRING TIME',3X,'DEVIATION',2X,'OVERLAPS',/)
        DO 350 JJ=1,M
       WRITE(8,360) JJ,XM(JJ),SD(JJ),CHECKER(JJ)
  360   FORMAT(5X,I3,4X,F6.2,8X,F6.2,3X,F6.0)
  350   CONTINUE
```

```
C      ------------------------------------------------------------ ---
C      Repeat of results for screen display
C      ------------------------------------------------------------
       WRITE(*,310) TITLE
       WRITE(*,320)
       WRITE(*,330) M, N, TAU, THRESHOLD, Z
       WRITE(*,300)P
       WRITE(*,340)
       DO 351 JJ=1,M
      WRITE(*,360) JJ,XM(JJ),SD(JJ),CHECKER(JJ)
 351   CONTINUE
       WRITE(*,300)P
       END
C      ------------------------------------------------------------
C      RANDOM NUMBER GENERATOR
C      ------------------------------------------------------------
        FUNCTION RND(Z)
        REAL*8 ASEED,X,PI
      DATA PI/3.1415926535898D0/
      IF(Z.EQ.0.0) GO TO 1
      ASEED=Z
 1      X=(ASEED+PI)**5
      ASEED=X-DINT(X)
      RND=SNGL(ASEED)
      RETURN
      END
C
C        ------------------------------------------------------------
C
```